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Memo

DATE: *August 20, 2004*

TO: RHIC E-Coolers

FROM: *Ady Hershcovitch*

SUBJECT: **Minutes of the August 20, 2004 Meeting**

Present: Ilan Ben-Zvi, Rama Calaga, Peter Cameron, Yury Eidelman (ORNL & BINP Novosibirsk, Russia), Alexei Fedotov, Wolfram Fischer, Ady Hershcovitch, Animesh Jain, Vladimir Litvinenko, Derek Lowenstein, William Mackay, Nikolay Malitsky, Christoph Montag, Thomas Roser, Richard Talman (Cornell University) Dejan Trbojevic, Grigory Trubnikov (Dubna, Russia), Jie Wei.

Topics discussed: Computations and Simulations, Solenoid Alignment

Computations and Simulations: the meeting started with a presentation, by Richard Talman from Cornell University on the Cornell ERL, and on an analytic accelerator model Nikolay Malitsky and he had developed. That model showed good agreement with simulations by the PARMELA code. Most of his presentation, however, focused on computations and simulations of the BNL electron beam-cooling stretcher. In particular he showed effects of coherent synchrotron radiation (CSR) and centrifugal space charge force (CSCF) on emittance and energy spread as the electron beam passes through a stretcher section.

Results of his simulations showed that the effects CSR combined with CSCF have on the electron beam as it passes through the stretcher are increase in beam emittance and growth in energy spread. Answer to Alexei's question was that the simulation is that of an electron beam in free space. Alexei pointed out that the beam pipe would reduce growth in emittance and energy spread. Ilan and Thomas thanked him for bringing this issue and concluded that simulations are needed for realistic condition that includes the beam pipe (where Eddy currents tend to suppress these growths).

Solenoid Alignment: the meeting continued with Pete's presentation on "e-Cooling Solenoid Beam-based Alignment." It was a very comprehensive talk on a solution to a hard problem, since co-linearity of ion and electron beams should be about 20 microns, with co-angularity of ion and electron beams of micro-rad. The method is based on measuring and shimming, BPM measurement of beam positions and 'Quad' modulations. Its diagnostics consist of a 3-D Hall probe system, a magnetic needle and mirror system, and an array of NMR probes. The alignment method seems feasible, and it can be performed in about 5 – 10 minutes. Below is Pete's presentation.

e-Cooling Solenoid Beam-based Alignment

Peter Cameron

August 20, 2004

Conclusions

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- We (Diagnostics) would like to ease the task of the Magnet builders as much as possible.
- Present goal is to develop a method which permits beam-based correction of field errors, at reasonably frequent intervals (whenever wanted) with minimal disruption of machine operations
- Sliding BPM appears possible, still at a very early conceptual design stage
- ‘Quad’ modulation also appears possible (and perhaps most desirable solution), similarly very early in conceptual design

Outline

- Statement of the Problem
  - ***AP requirements***
  - Solenoid preliminary design
- Solutions
  - Measure and Shim
  - BPM measurement of beam positions
  - 'Quad' modulation

E-Cool Solenoid Diagnostics

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- Few month timescale (solenoid design decisions)
- 5 dimensional space?
  - co-linearity of ion and electron beams **~20μ**
  - co-angularity of ion and electron beams ~1μrad?
  - longitudinal - velocity and phase match
  - transverse - envelope match
- Initial tuning
  - BPMs at solenoid ends
  - BPMs within solenoids – every 15cm or less to match correctors
- Refined tuning – recombination monitor (beam dump)
  - 1% of beam - ~MHz rates
  - PMT? MCP? Need design study (Kewish, Gassner, Connolly,…)

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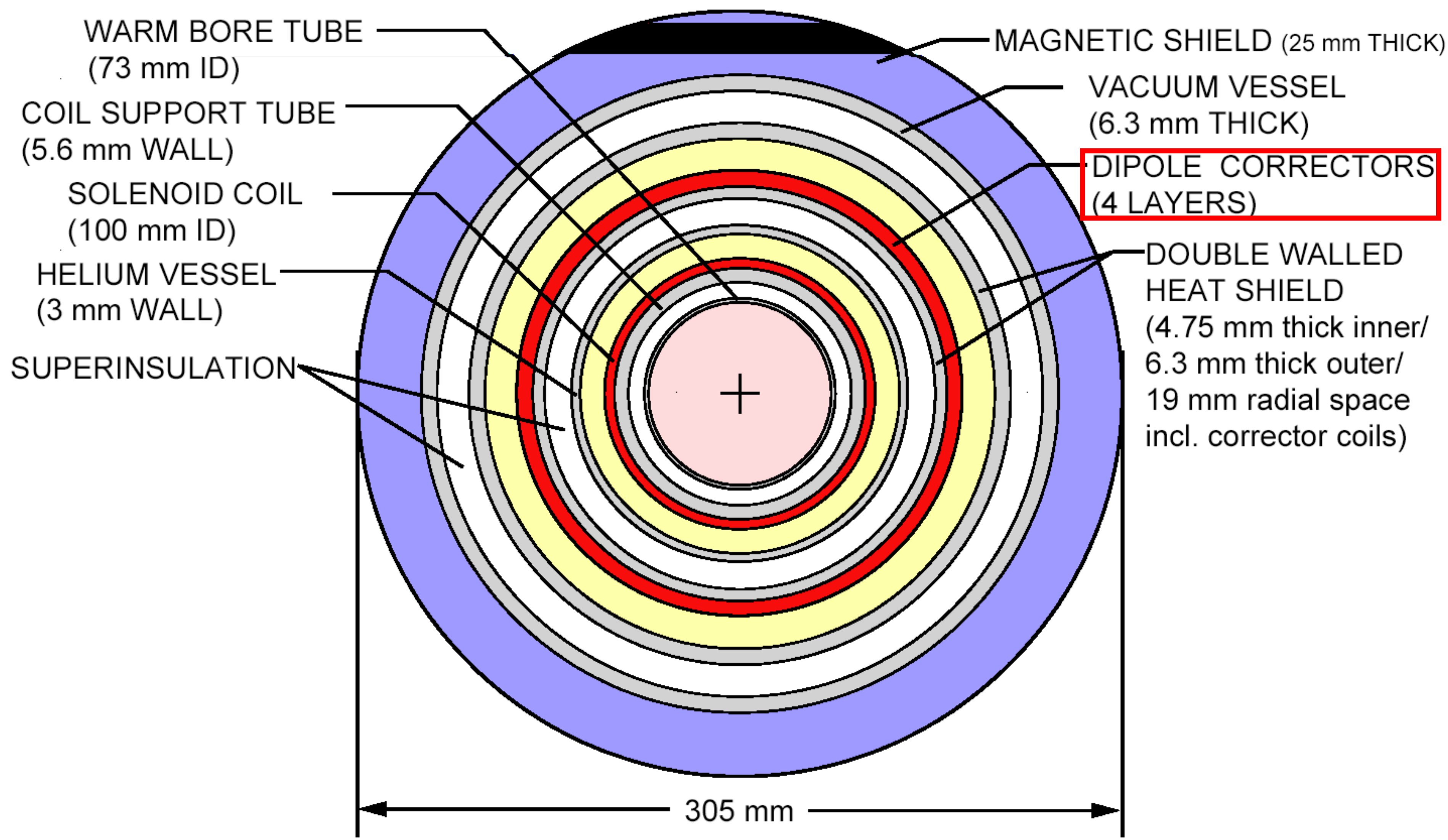
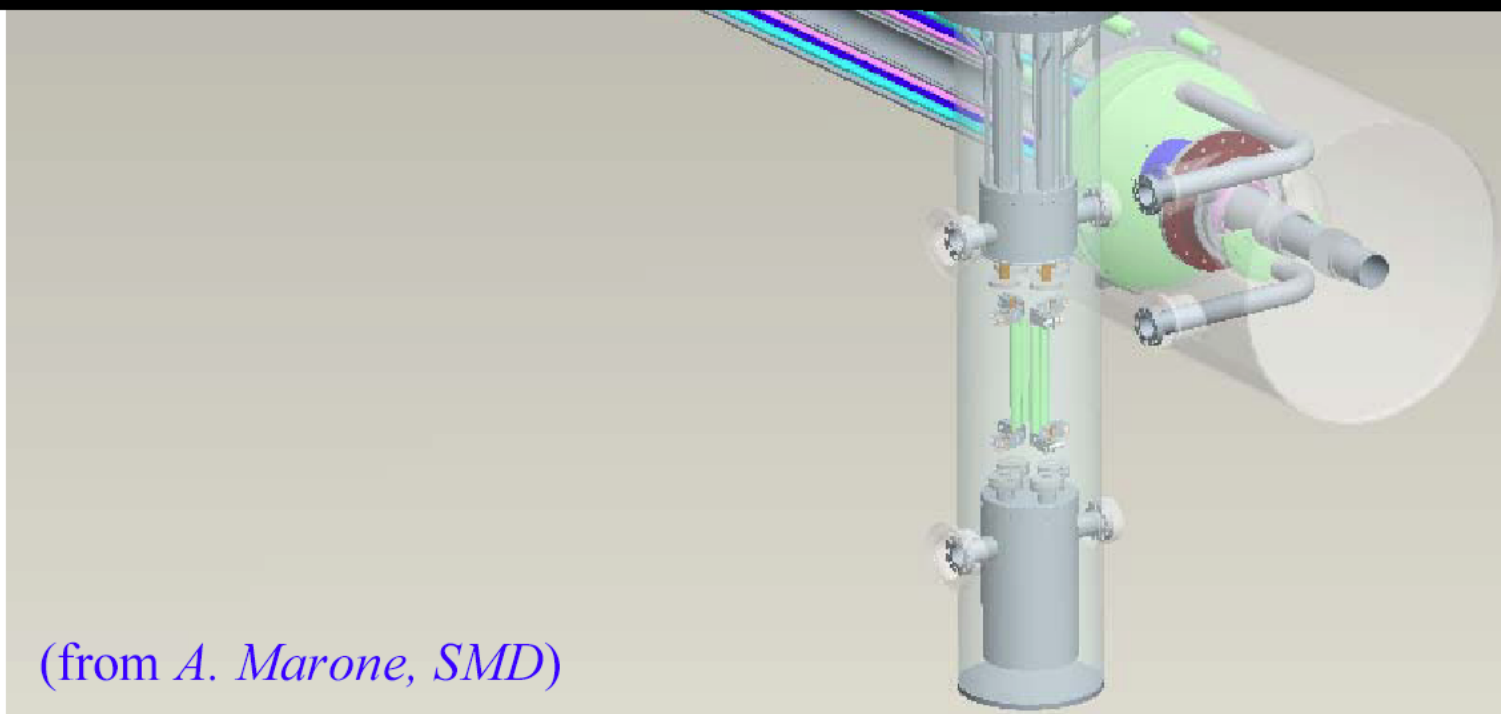
Solenoid Cross Section

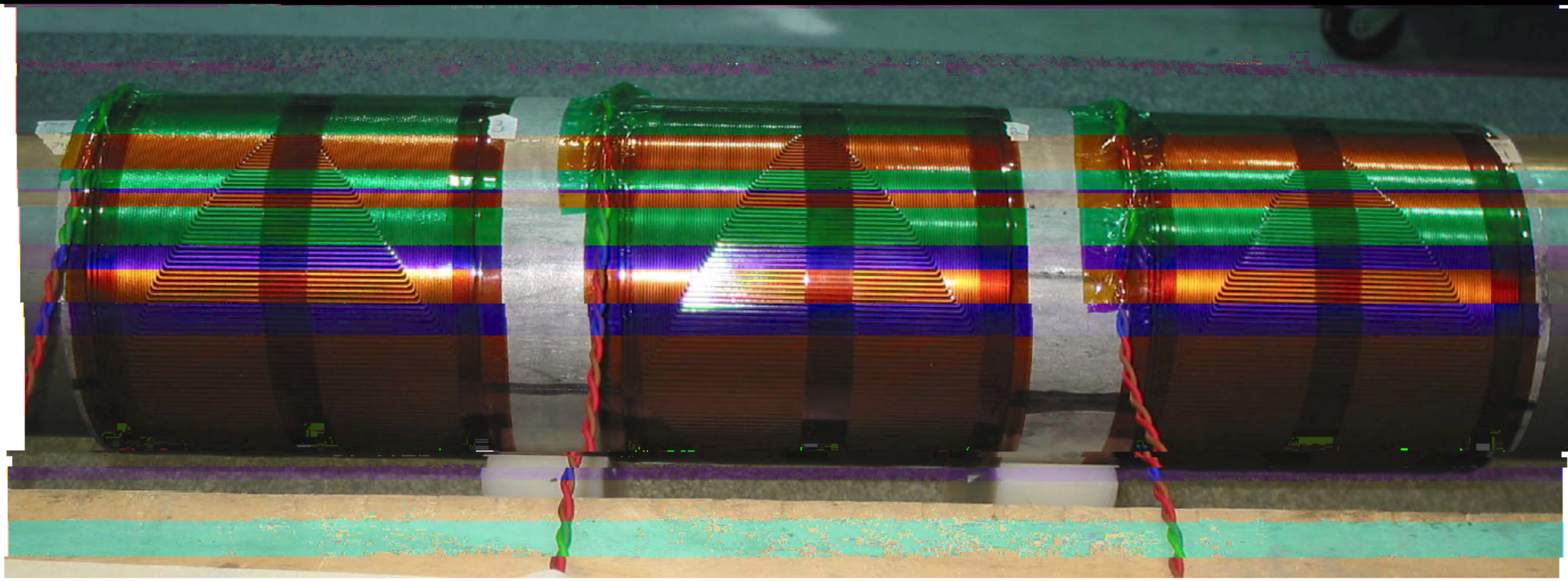




(from *A. Marone, SMD*)

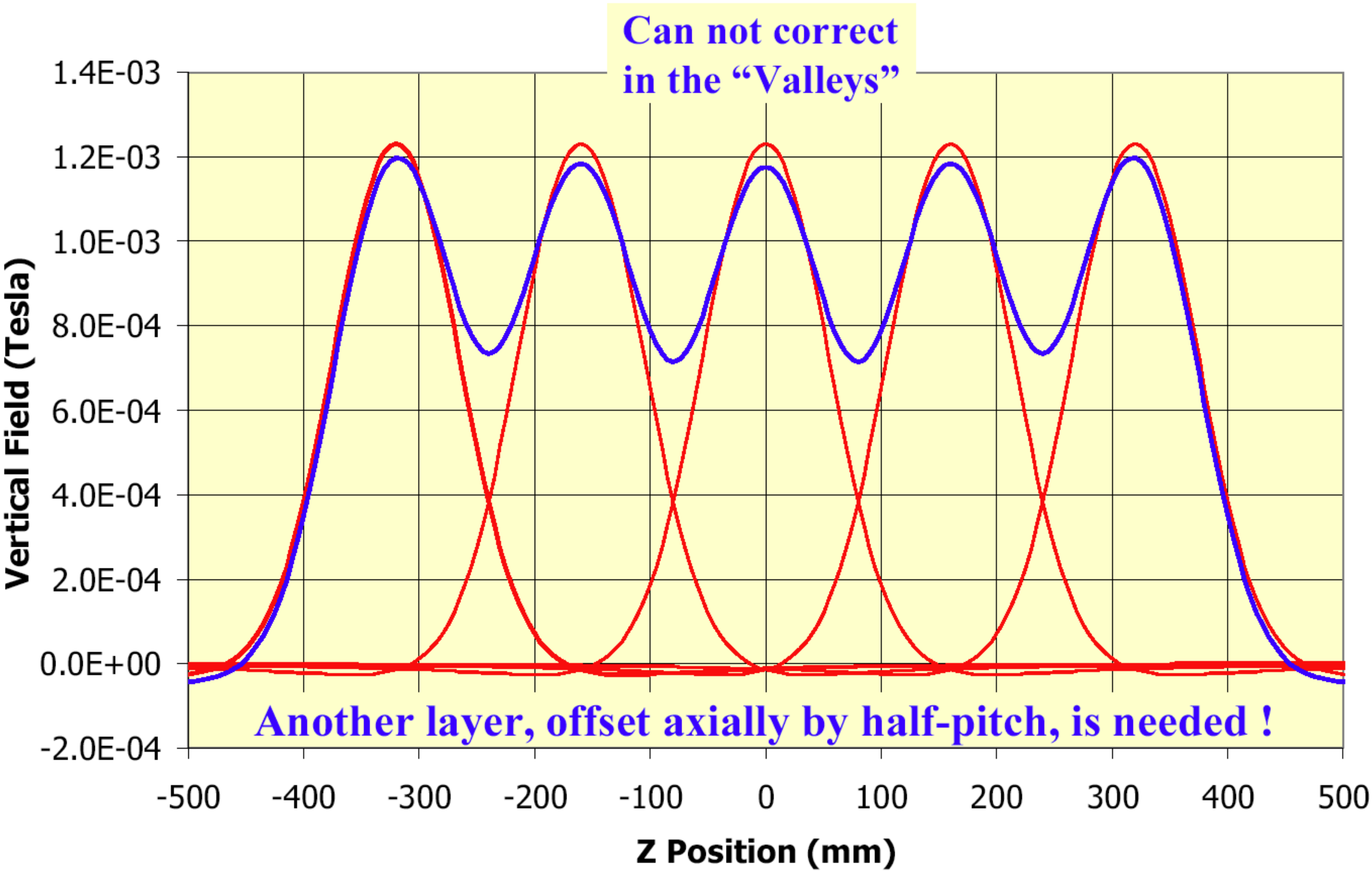
Dipole Correction Coils

- $B_\perp / B_z \sim 10^{-5}$ implies a straightness of 10 μm over 1 meter length. This may not be achieved with mechanical alignment alone.
- Winding imperfections are also likely to produce transverse fields on-axis.
- Goal is to achieve as close to 1×10^{-5} as possible with construction tolerances and mechanical adjustment (expect ~ a few × 10^{-4})
- Correct the remaining errors with an array of ~ 150 mm long, printed circuit dipole correctors.
- **Two sets of correctors *per axis* are required.**

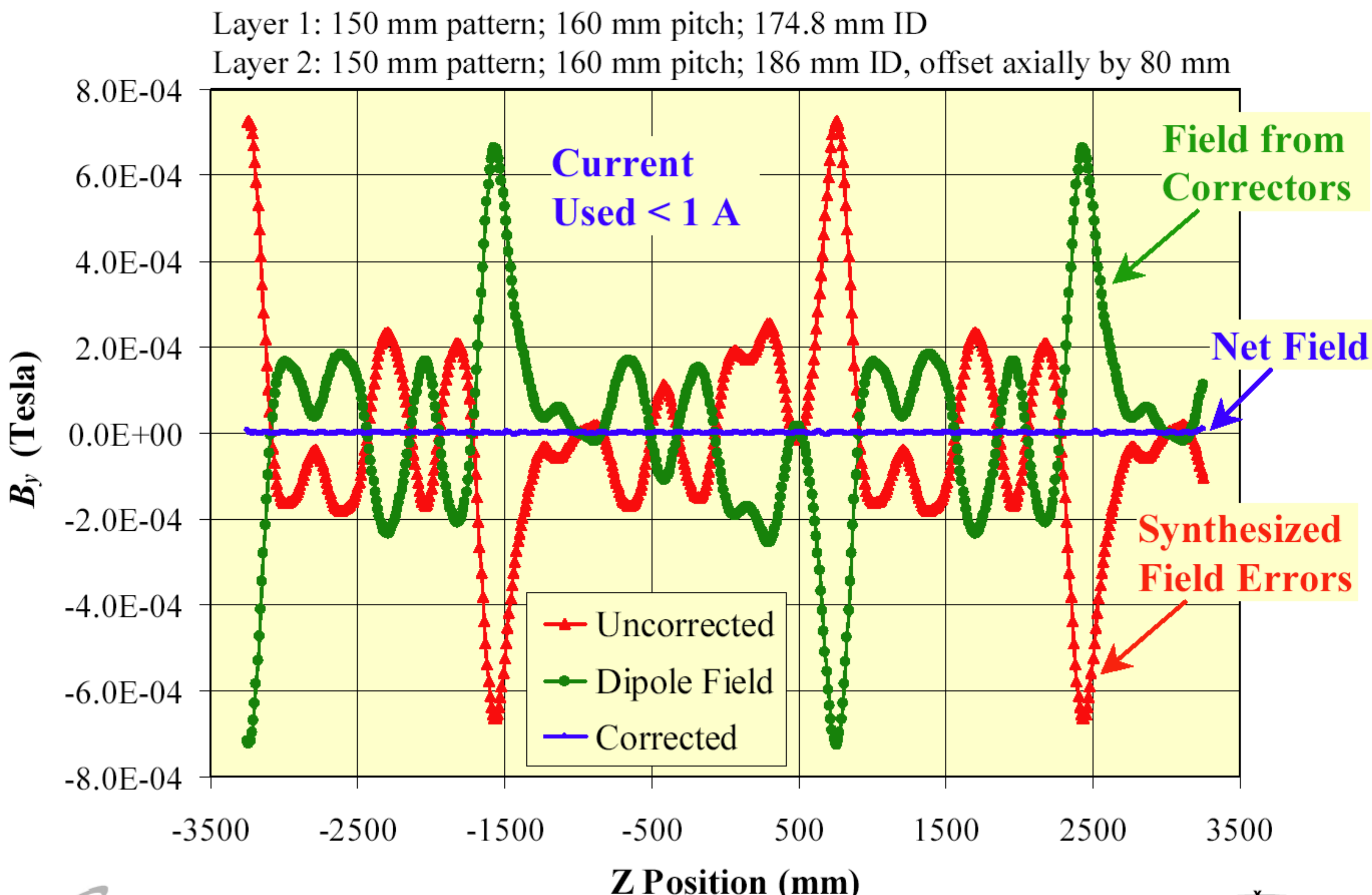


- 2 Layers of 4 oz Copper patterns; 159 mm ID, 150 mm long
- 1.25×10^{-3} Tesla central field at 2 A; $\Delta B/B \sim 10^{-3}$ at 50 mm
- Mounted on cryogenic heat shield to minimize dissipated power (approx. 190 W/m expected at full power).

Array of 150 mm long Correctors, 160 mm apart

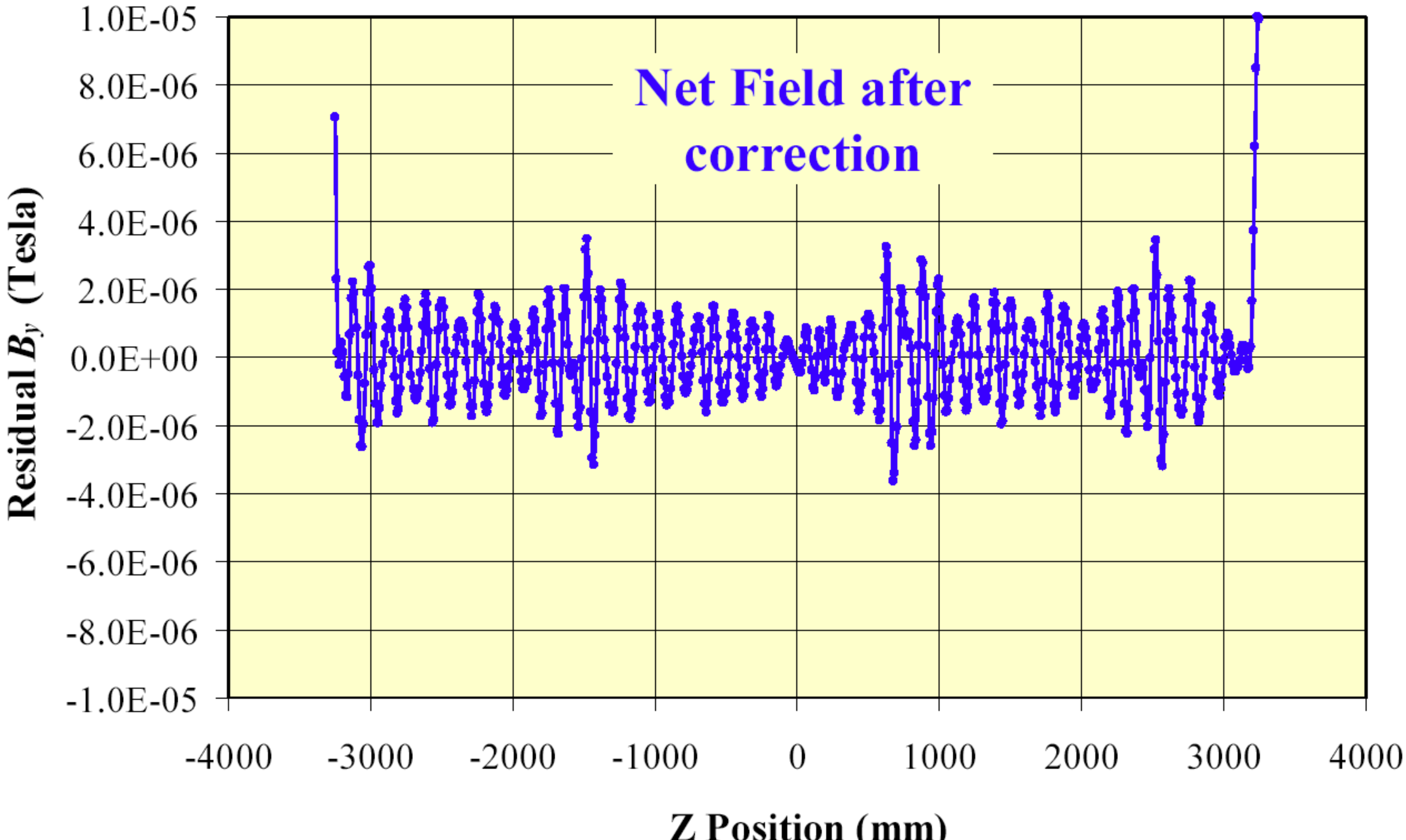


Simulation to Check Correction Algorithm



Simulation to Check Correction Algorithm

B_y Error data;20 harmonics; Lambda=100mm to 2 meters; 6.5m long solenoid; ~6.6m long corrector
2 families; Dipole06a;b; 150mm patterns. 160mm spacing; 80mm offset for second layer; No extra gaps.



Outline

ERL

- Statement of the Problem
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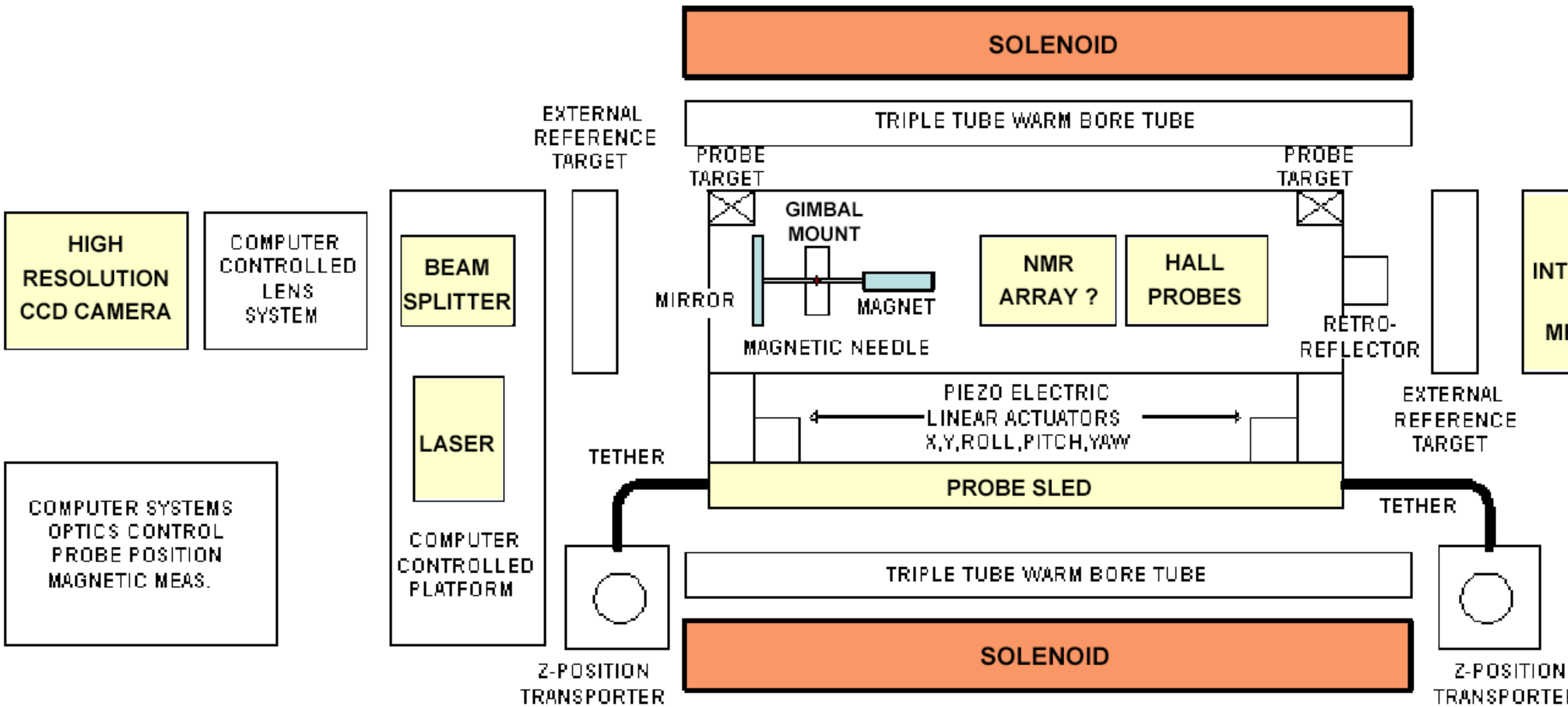
- Solutions
  - ***Measure and Correct***
  - BPM measurement of beam positions
  - ‘Quad’ modulation

[redacted]

Measurement System Schematic



(from *George Ganetis, SMD*)

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BPMs within Solenoid?

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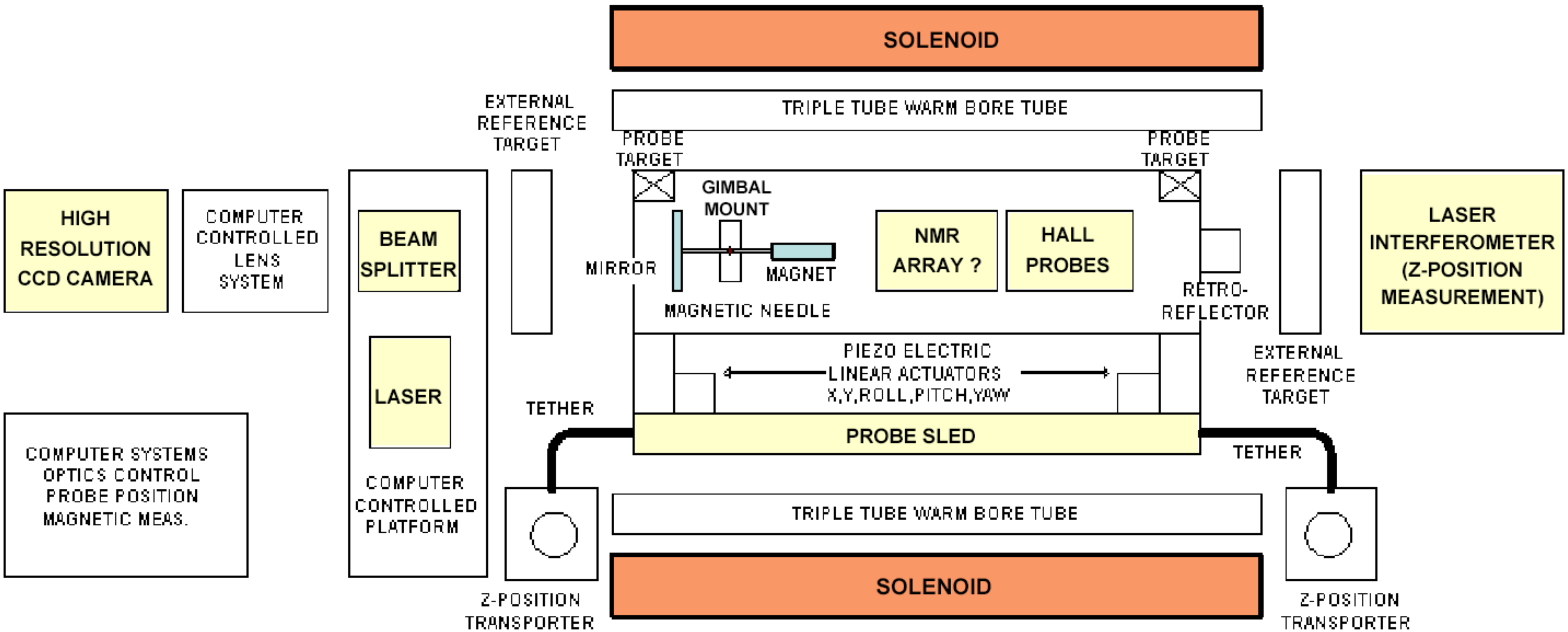
- ‘Conventional’ 50 ohm striplines?
- Continuous Stripline with dielectric?
- Traveling wave pickup?
- Squids?
- ***Sliding BPM - only practical solution to requirement for ~90 BPMs/solenoid***

Measurement System Schematic



(from *George Ganetis, SMD*)

Sliding BPM

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- Ceramic cylinder ~10 cm long x 6cm ID with striplines plated on ID (limiting aperture, beam scraping,…)
- X-Y orientation? How crucial?
- How to get signals out? Vacuum requirements?
  - Coax rigidity is a problem
  - Wireless? Need to be above cutoff, mixers, power,…
  - Diode detect and bring out on twisted pairs? 10MHz BW?
- Bandwidth requirement
  - Measure both beams simultaneously?
  - Phase shift one beam? 120 bunches gives ~50ns

Simultaneous Measurement

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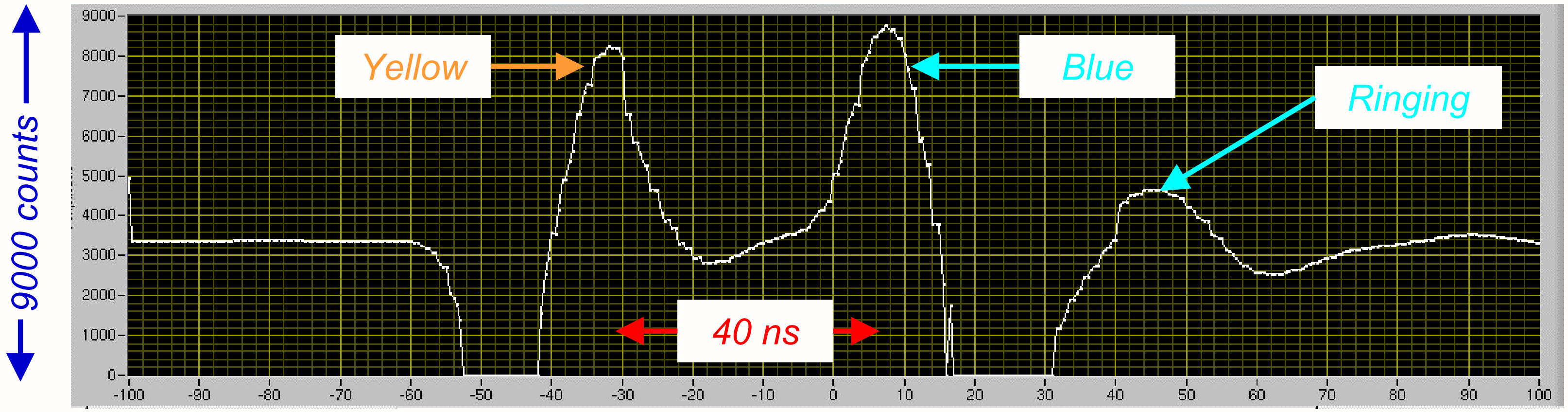
Null Measurement Procedure

- Properly phase ion and electron beams
- Four bump ion beam (fiducial), record ion beam position at minimum signal (implies ion-only bpms)
- Move bpm and repeat,…



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Basic Method

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- Wind dipole correctors so that they can be externally switched to quad configuration (or add additional quad windings)
- Modulate quad at a few Hz
- Scan beam ~ +/- 5mm across quad aperture
- Monitor power at mod freq on suitable BPM(s)
- Do this with both ion (fiducial) and e^- beams
- You now have relative position measurement
- Animesh inserts position values in his transfer matrix and inverts to get corrector strengths

The 'Quad'

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- Assume $2x10^{-3}$ T at winding, 15 cm diameter gives gradient of ~ .026 T/m
- Assume max modulation frequencies ~5-10Hz (eddy currents in quad windings and shielding by solenoid need to be analyzed)
- Possibility of higher gradients in pulsed mode can be considered - limit shifts from heat load on LN2 to bond strength of conductor to substrate.

Ion Kick Amplitude 1

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Beam offset in quad gets kicked. Magnitude of kick is

$\theta = k \cdot L \cdot y \sim \mathbf{0.4\ \mu rad}$ where

g = quad gradient ~ 0.026 T/m

p = beam momentum ~ 10 GeV/c

k = quad strength = .2998 g/p ~ 0.0004 m^{-2}

L = quad length ~ 0.1m

y = beam offset ~ 5mm

Effective B ~ $g \cdot y$ ~ 6 gauss at 5mm

BBA measurement resolution

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β_{kicker} ~ 60m, β_{pickup} ~ 100m,

sqrt($\beta_k\beta_p$)θ ~ 30μ, (60μ p-p)

BPM 1000 turn resolution ~1μ,

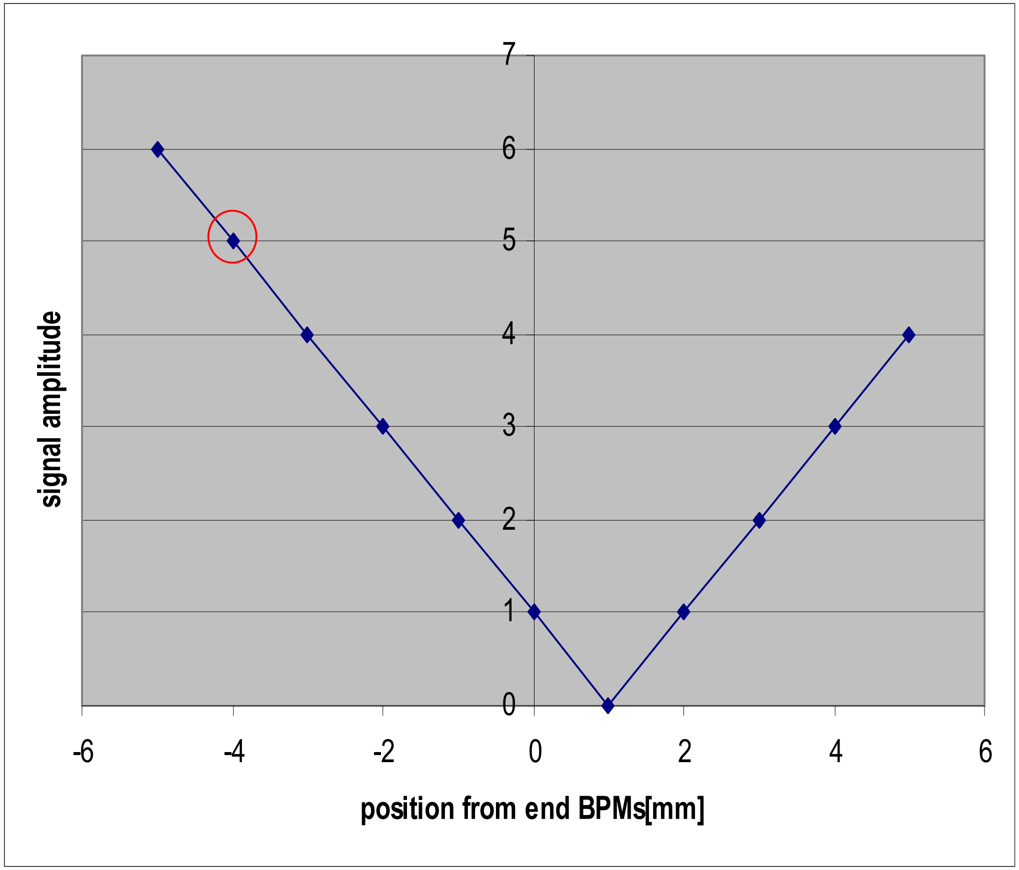
10^5 turns ~ 0.1μ

One part in 300

So single point resolution is

~ 5mm x (0.1/30) ~ **15μ**

But BPM is not optimized for this measurement, we can do better



Measurement resolution 2

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look at 28MHz, harmonic 360 (Shafer)

$n := 360 \qquad \omega_0 := 78000 \cdot 2\pi \cdot \frac{1}{sec} \qquad \sigma := 7 \cdot ns$

$A_n := e^{\frac{-n^2 \cdot \omega_0^{\,2} \cdot \sigma^2}{2}} \qquad A_n = 0.466433$

$I := \left(10^{11} \cdot 1.6 \cdot 10^{-19} \cdot coul \cdot 78000 \cdot \frac{1}{sec}\right) \qquad I \cdot 60 = 0.07488\,amp$

$\omega := 28000000 \cdot 2 \cdot \pi \cdot \frac{1}{sec} \qquad L := 25 \cdot cm \qquad c := 3 \cdot 10^8 \cdot \frac{m}{sec}$

$P_{signal} := 2 \cdot \left(\frac{70}{360}\right)^2 \cdot 50 \cdot ohm \cdot 60 \cdot (I)^2 \cdot A_n^{\,2} \cdot \sin\left(\frac{\omega \cdot L}{c}\right)^2 \qquad P_{signal} = 1.6404 \times 10^{-6}\,watt$

$P_{noise} := 10^{-19} \cdot watt$ BW 1Hz, 14dB noise figure, losses... $b := 10 \cdot cm$

$\delta x := \frac{b}{4} \cdot \sqrt{\frac{P_{noise}}{P_{signal}}} \qquad \boxed{\delta x = 6.172558 \times 10^{-9}\,m}$

6nm resolution on position measurement, Less than 1μ on BBA

Reality check 1 - RHIC BPM

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reality check

$P_{noisebpm} := P_{noise} \cdot 2 \times 10^{7}$

BW 20MHz, 14dB noise figure, losses,...

$\omega := 10000000 \cdot 2 \cdot \pi \cdot \frac{1}{sec}$

$n := 120$

$A_n := e^{\frac{-n^2 \cdot \omega_0{}^2 \cdot \sigma^2}{2}}$

$P_{signalbpm} := 2 \cdot \left(\frac{70}{360}\right)^2 \cdot 50 \cdot ohm \cdot (I)^2 \cdot 200 \cdot A_n{}^2 \cdot \sin\left(\frac{\omega \cdot L}{c}\right)^2$

single bunch,
~200 lines

$\delta x_{bpm} := \frac{b}{4} \cdot \sqrt{\frac{P_{noisebpm}}{P_{signalbpm}}}$

$\boxed{\delta x_{bpm} = 2.14255 \times 10^{-5} m}$

~21μ BPM resolution, we observe ~25-30μ

Reality Check 2

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Reality check - cryostat vibrations

Gradient ~ 50T/m, length ~ 3m, vibration amplitude ~ 0.4µ

- Bl ~ 60µT-m
- δx ~ 300µ p-p

This compares with solenoid 'quad'

- Bl ~ 12µT-m
- δx ~ 60µ p-p

Sources of error

- Fiducialization of 'quads' - ion beam measurement
  - BPMs at cryostat ends ~ a few microns
  - Ion beam position in quad ~ 1 micron
- Electron Beam position
  - BPMs at cryostat ends - co-locate ion and electron beams via nulling method? ~ a few microns (multiplex? See below)
  - electron beam position in quad ~ a few microns?
  - **But -** solenoid mixes x and y, complicates position scan of electron beam, interpretation of position data. This requires further study to develop a workable algorithm
- Time/Temperature drift of ion beam measurement – main source?
- Errors will add in quadrature (?), so (given a method to untangle solenoid effect on electron beam) , with some conservativism (!) co-alignment of better than 10μ seems possible!

Measurement Time

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- 1 sec/measurement, 1 sec/position shift, 6 points/scan this gives ~15 sec/plane, 30 sec/corrector location
- 90 correctors x 2 solenoids = 180 correctors this gives 90 minutes for fiducialization
- But can do more than one corrector location at a time by modulating at different frequencies. If we have ~6Hz BW of quad modulation, then we require **~15 minutes for fiducialization** (at injection?)
- S/N for electron beam can be better (less rigid, more kick), so one can imagine **5-10 minutes required for solenoid filed correction**

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